

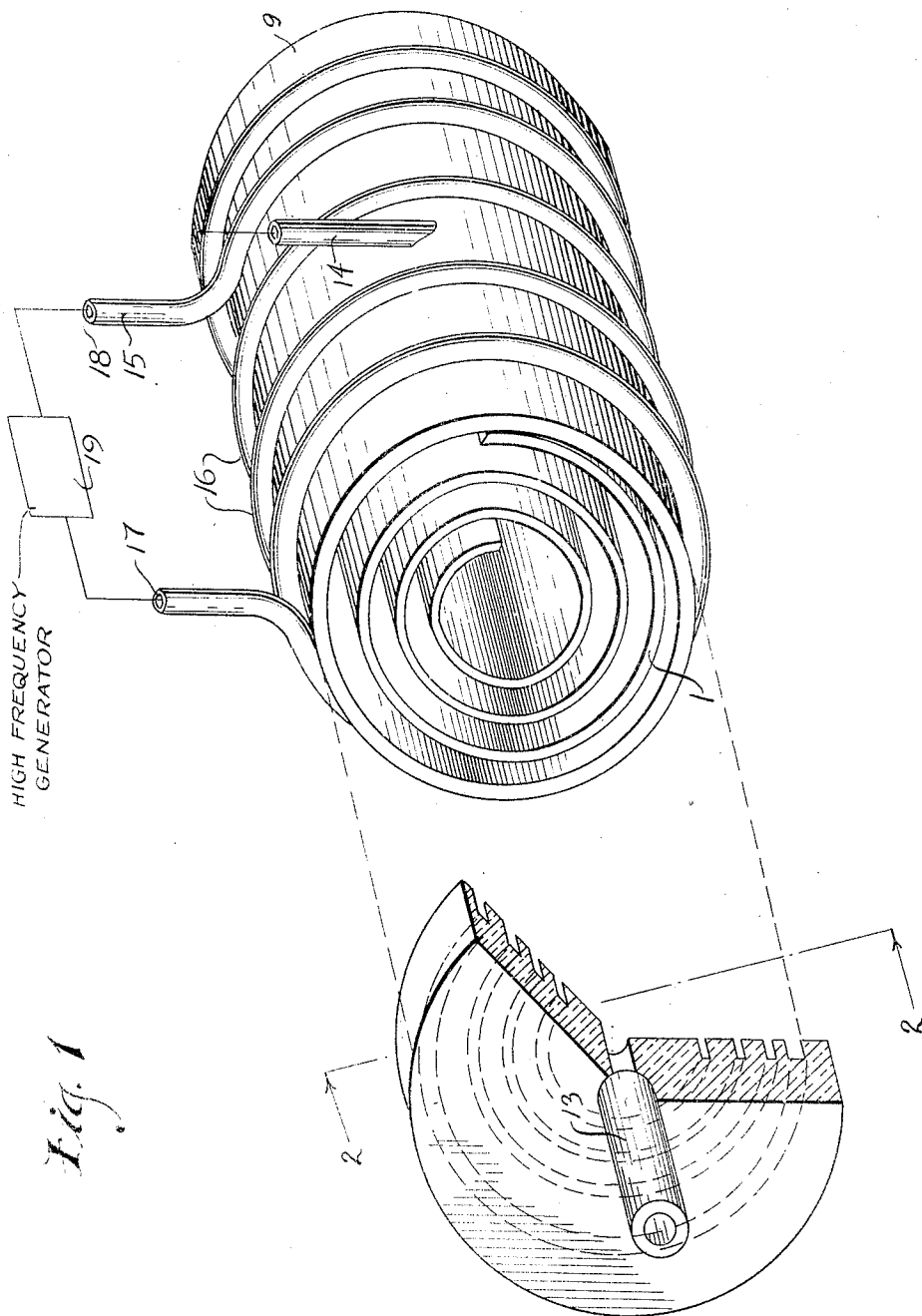
Jan. 17, 1950

E. K. McMAHON ET AL
METHOD AND APPARATUS FOR TREATING
MATERIALS DIELECTRICALLY

2,494,716

Filed Nov. 8, 1945

3 Sheets-Sheet 1



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Fig. 3

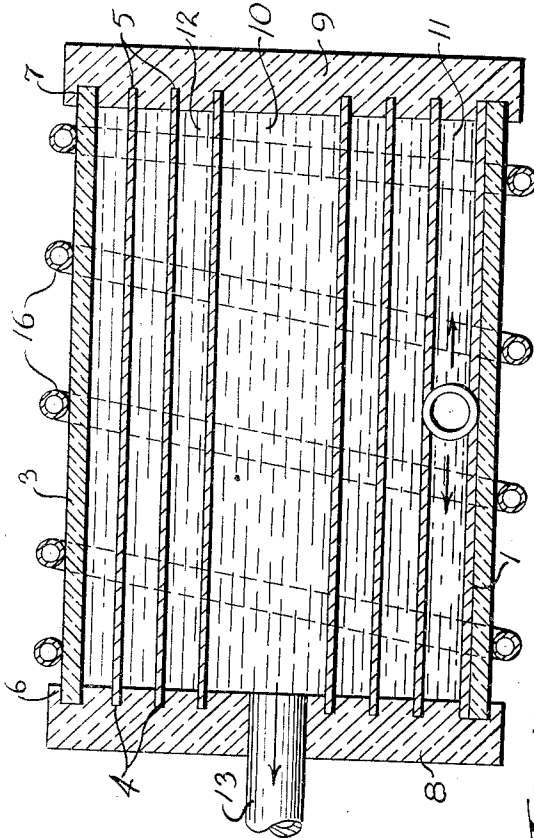


Fig. 5

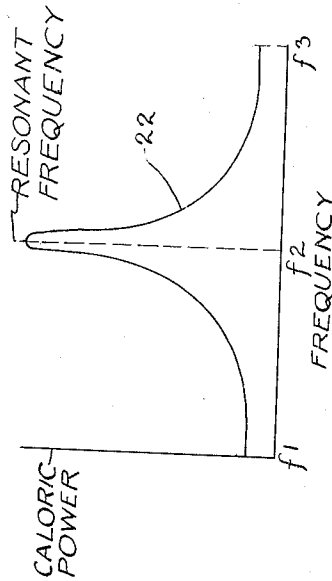


Fig. 2

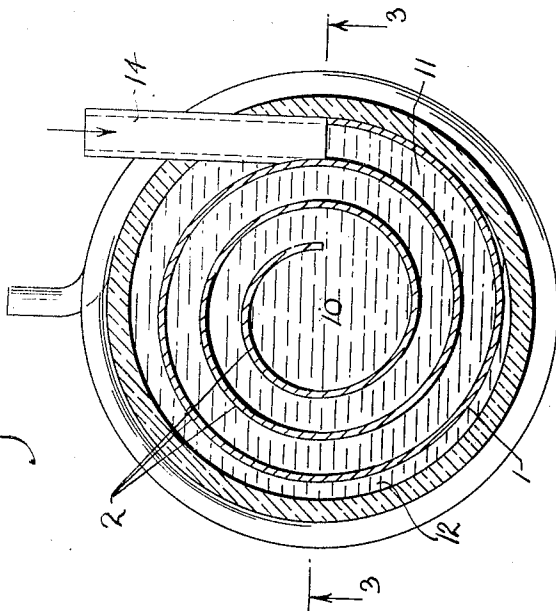
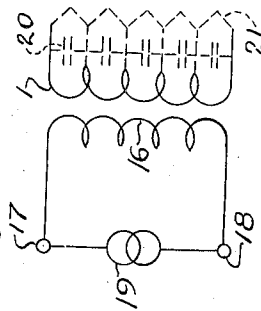


Fig. 4



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Fig. 6

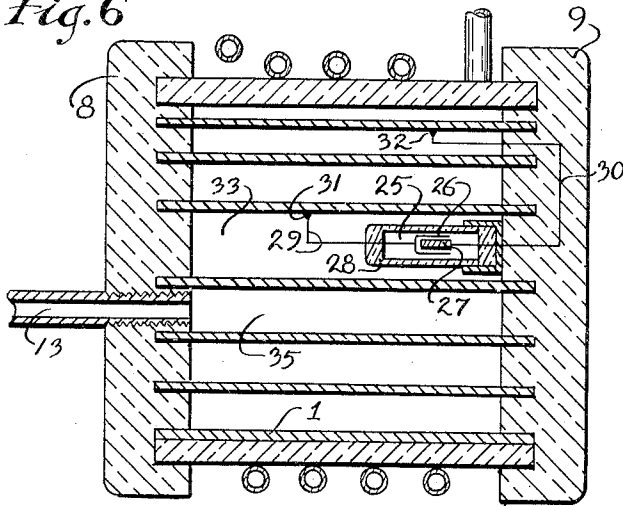


Fig. 7

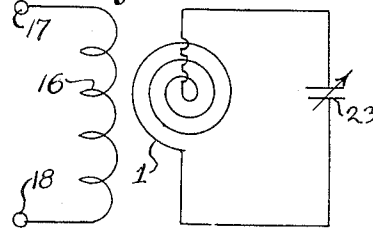


Fig. 8

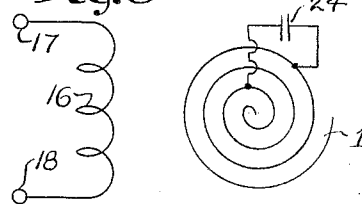


Fig. 9

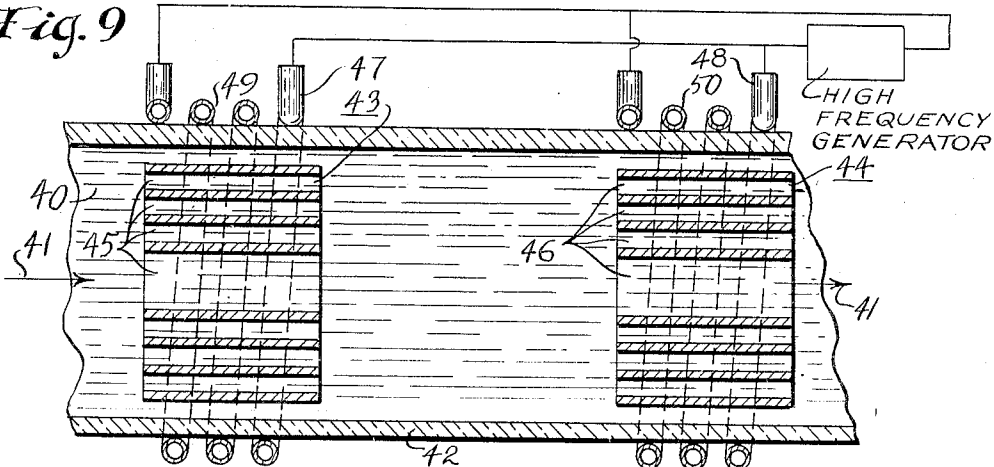


Fig. 11

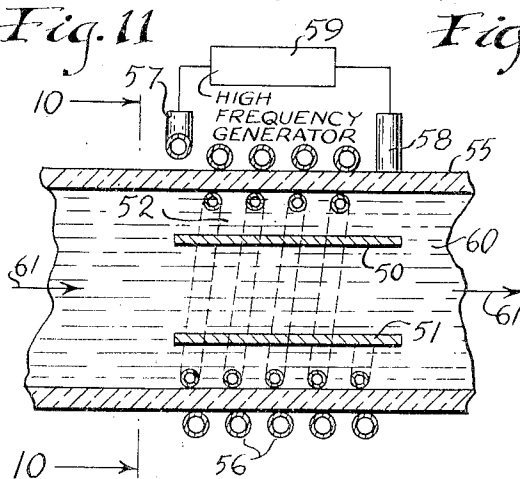
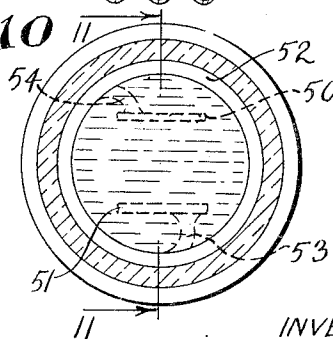


Fig. 10



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METHOD AND APPARATUS FOR TREATING
MATERIALS DIELECTRICALLY

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8 Claims. (Cl. 219—47)

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This invention relates to methods and apparatus for dielectrically heating emulsions and other liquids, liquid mixtures, pastes, etc., and masses of divided solid material. Among other uses the invention is particularly adapted for heating, drying or breaking down of emulsions, or separating liquid mixtures or solutions into their components, etc.

According to a principal feature of the invention, methods and apparatus are provided for dielectrically heating various materials, such as above specified by means of one or more magnetically energized conductors preferably of a spiral configuration and such as to have a relatively large amount of distributed capacity and adapted to be traversed by the material to be treated.

In the drying of mixtures such as emulsions or similar materials containing water, it is necessary to first raise the temperature of the water phase to its boiling point at the pressure being used, and thereafter to supply enough heat to vaporize and distil off the water.

If this heat is supplied by the usual direct or conductive heating methods, the success of the process is determined by several factors. For example, if the material being treated is a poor conductor of heat, the process may be very slow even if a high temperature source of heat is applied. Furthermore, in such cases the temperature gradient from the surface inwardly may be sufficiently high to produce localized overheating of and injury to the material being treated.

If in addition to being a poor thermal conductor, the material contains some component that is heat-sensitive, that fact must be taken into consideration in determining the temperature of the applied heat, and the process must accordingly be carried on more slowly and at a lower temperature than otherwise. If the critical temperature is in the neighborhood of the boiling point of the water, where water is a constituent to be removed, the permissible temperature applied may be so low that very little water is vaporized at normal pressures, whereby special vacuum drying processes become necessary.

We have discovered a practical and efficient way by which these difficulties may be minimized or avoided by heating emulsions and similar materials dielectrically, that is, by subjecting same to an electrostatic field maintained by the use of high voltage alternating current of a frequency, for example, in the neighborhood of one to forty megacycles or even higher, and preferably in the range of about ten to twenty megacycles, employing for this purpose, the special procedures and apparatus of the present invention.

Most emulsions consist of dielectric materials the components of which may be selectively heat-

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ed to a fairly pronounced degree. The degree of heating of a dielectric, when subject to a high frequency electrostatic field, is substantially proportional to the product of the dielectric constant and the power factor of the material, viz., the so-called "loss factor." For example, in a water and oil emulsion, the oil will ordinarily have a low "loss factor," whereas the water will have an exceptionally high "loss factor" due to the fact that both its dielectric constant and its power factor are high. This unusual property makes it possible to selectively heat and remove the water in water-oil emulsions and the like, without the delays and hazards incident to conductive heating procedures; also without substantially heating the components other than the water, and without having to apply any hot surface to any part of the material. In the case of a water and oil emulsion, we have found that it is possible to thus selectively heat the water enough to cause a substantial portion or even all of the water to vaporize and boil off before the remainder of the emulsion reaches the boiling point of water. By this method emulsions may be dried in a matter of a few minutes, which heretofore could not be satisfactorily dried without injury or required a long careful and tedious drying process of many hours.

Heretofore it has been the general practice in dielectric heating to place the material to be treated between a pair or pairs of spaced electrodes forming condenser plates to which a source of high frequency voltage is connected. While it is possible to treat emulsions and the other materials above mentioned by using such spaced electrodes immersed therein, yet the potential gradient is likely to be very high in regions adjacent to such spaced electrodes, difficulties may be encountered due to arcing, sparking and sputtering of the liquid around the electrodes. We have discovered, however, that if instead of using a pair of spaced electrodes, a single continuous or substantially continuous conductor is immersed in the dielectric to be heated, and if the conductor is so constructed and arranged as to provide a substantial amount of distributed inductance and capacity in conjunction with the dielectric material in which it is immersed, then the high frequency current may be applied to the terminals of this conductor with the result that the dielectric material may be heated with surprising rapidity without any arcing, sparking or other difficulties. By the same expedient, bodies of plain water and aqueous solutions may be rapidly and efficiently heated.

In our application, Serial No. 570,598, filed December 30, 1944, now Patent Number 2,446,557, dated August 10, 1948, we have described various constructions for dielectrically heating emulsions and other liquids in accordance with the princi-

ples above outlined, employing for the purpose, one or more continuous conductors immersed in the dielectric and arranged to provide a substantial amount of distributed inductance and capacity, thereby to minimize localized overheating, sparking, etc. For example, in accordance with certain modifications of the aforesaid application, the conductor or conductors employed for purposes of heating the emulsion or the like, may take the form of metal strips wound spirally to provide spaced convolutions with terminal conductors connected to the inner and outer ends thereof for purposes of impressing the necessary high frequency voltage therebetween.

In accordance with a further aspect of said application, such a spiral heating element may be arranged in a cylindrical compartment containing the emulsion to be heated, and for purposes of the continuous operation, the emulsion may be caused to flow axially through the spiral, whereby the drying thereof is affected as a continuous and uninterrupted operation. With this arrangement, however, the liquid being heated is subjected to the electrostatic stress between the turns of the spiral for only a comparatively short period of time, as determined by the axial length thereof.

In accordance with a preferred modification of the present invention, a substantial improvement in the use of such spiral conductors for the drying of emulsions and the like, may be affected by means of constructions according to which the spiral conductor or conductors is or are energized magnetically, and in an arrangement such that the material being treated is caused to pass through the spiral conductor from the outside turn, spirally down through the conductor, being removed at the center, or vice versa. With this arrangement, no connections from the energizing source to the spiral are required, and any given molecule of the liquid is subjected to the electrostatic field for a considerably longer period of time for a spiral of given dimensions, since in general, a path spirally therethrough is considerably longer than the axial path.

In order to provide the aforesaid construction in a practical way, a spiral of metal strip is wound in spaced convolutions and the lateral edges of the spiral are closed off, as by embedding in discs of an insulating material, such as synthetic resin, for example, Bakelite, polystyrene, etc. or porcelain, insulating cement, etc. Preferably also, a tubular housing of similar insulating material is provided around the spiral proper, this tubular housing likewise terminating at and being preferably embedded in the insulating end pieces, thereby to provide a completely fluid tight compartment. A pipe connection enters axially through one of the insulating end pieces for access in the innermost convolution of the spiral; while a second pipe connection is preferably tapped tangentially through the tubular portion of the housing for access to the outer convolution of the spiral. In this way, the flow of the material to be treated may be arranged to enter through the first mentioned pipe connection to the inner convolution of the spiral, being thereupon forced to traverse successive convolutions thereof, until it ultimately passes out of the equipment through the tangential pipe connection above mentioned. Or the direction of flow may be reversed, such that the material being treated enters the apparatus through the tangential pipe connecting with the outermost spiral convolution, the material passing thence down

along the spiral to the inner convolution and passing out through the axially extending pipe.

For purposes of energizing the apparatus, a conductor is wound about the outer tubular portion of the insulating housing a sufficient number of turns to provide an energizing coil of appropriate value; or, alternatively, if the tubular housing is omitted and only the insulating end plates employed with the spiral, an insulated conductor may be wound about the spiral for inductively energizing the same. The terminals of this coil are extended to the terminals of a high frequency generator of a frequency as above stated.

With this arrangement, the high frequency current traversing the outer coil connected to the generator, induces a voltage of like frequency between each segment or sector of the successive convolutions of the inner spiral, by virtue of the magnetic flux linking the same and resulting from the current flowing in the outer coil connected to the generator. Thus, the spiral coil functions as the secondary winding of a two-winding transformer, the primary of which is the outer coil connected to the generator. The arrangement has the novel advantage that no electrical connections extend to the spiral, or through the chamber housing the same where employed, high frequency energy being applied to the spiral electrode exclusively by electro-magnetic induction. The spiral heating element may therefore be completely sealed up in the insulating housing, except for the entry and exit pipe connections above mentioned.

The aforesaid feature of the invention consisting in magnetically or inductively energizing electrodes for purposes of dielectric heating and the like, is, of course, not restricted to conductors of the specific construction above described, but is of general applicability and may be applied for example, to the energization of spiral conductors traversed in an axial direction by the material being treated or in accordance with other modifications of the invention described in detail hereinafter.

In the drawings:

Fig. 1 is a perspective view of the aforesaid preferred form of the invention, according to which the material being treated is spirally fed through the conductor structure, this view being partially exploded and partially in section in order to expose the internal construction of the apparatus.

Fig. 2 is a transverse section of the Fig. 1 modification taken substantially at 2, 2 of Fig. 1: while Fig. 3 is a horizontal longitudinal section thereof taken at 3, 3 Fig. 2.

Fig. 4 illustrates diagrammatically, the equivalent electrical circuit of an apparatus such as is shown in Figs. 1 to 3.

Fig. 5 depicts graphically the caloric performance of such apparatus at different frequencies.

Fig. 6 is a vertical longitudinal section of the Figs. 1 to 3 structure as modified to include a tuning condenser for adjusting the resonant frequency of the apparatus as desired.

Figs. 7 and 8 are semi-diagrammatic showings of the Fig. 6 modification, but illustrating different possible connections for the aforesaid tuning condenser.

Fig. 9 is a vertical longitudinal section of still another modification of the invention, according to which the emulsion, liquid, etc. to be treated is passed axially through one or more magnetically fed spirals, instead of spirally as in the modifications previously referred to.

Fig. 10 is a transverse section at 10—10 of Fig. 11; while Fig. 11 is a longitudinal section at 11—11 of Fig. 10 of still another modification of the invention employing other than the spiral conductor construction.

Referring to Figs. 1 to 3 inclusive in which like elements are similarly designated, the apparatus comprises a spiral conductor 1, comprising a strip of a metal having good electrical and heat conducting properties, such as copper, aluminum, steel, etc., wound in successive spaced convolutions, such as 2. The entire spiral conductor thus formed may optionally be housed in a tubular casing 3, of dielectric material, such as synthetic resin, porcelain, insulating cement, etc.

The lateral edges, such as 4, 5 of the spiral conductor 1, as well as the ends 6, 7 of the tubular housing 3 if used, are preferably embedded in cylindrical end pieces 8, 9 of a suitable low-electrical-loss and moldable dielectric material, such as the materials above mentioned.

It will be observed that the apparatus as thus constructed, provides a continuous, fluidtight spiral passageway extending between the innermost convolution 10 of the spiral and the outermost convolution 11 thereof. For causing a fluid to be treated, such as that indicated at 12, continuously to traverse this spiral passageway, a pipe connection 13 is tapped axially through the center of one of the end pieces, such as 8, to provide a passageway into the innermost convolution 10 of the spiral. Likewise a pipe connection 14 is preferably tapped tangentially through the tubular housing 3 for access to the outermost convolution 11 of the spiral, as shown more particularly in Figs. 1 and 2. Thus, the liquid to be treated, may be caused to enter the spiral through the axial pipe connection 13 and after traversing the spiral passageway, to leave through the tangential pipe connection 14, or vice versa. The tangential pipe connection 14 is preferably tapped through the tubular housing 3 at approximately the mid point longitudinally thereof, as illustrated for example, in Fig. 1.

For purposes of energizing the apparatus, a conductor 15 is wound in one or more turns about the tubular insulating housing 3 to provide an energizing coil 16, the terminals 17 and 18 of which are connected to the terminals of a high frequency generator 19 as shown in Fig. 1 and of a frequency as above mentioned. Conductor 15 may comprise insulated wire if the insulating tube 3 is omitted, or if present bare metal tubing, such as copper tubing may be used, through which a cooling fluid, such as water, may be circulated if desired or required.

With the construction as thus described, it will be observed that the spiral 1 is energized exclusively by magnetic induction from coil 16, there being no direct connection between the spiral and the source of high frequency energizing voltage 19. Accordingly, the spiral or heating conductor may be enclosed wholly within the insulating housing 3, 8, 9 as shown, and no perforations of any character are required in the housing for purposes of energizing the conductor.

It should further be noted in connection with the apparatus above described, that in the absence of any material to be heated, flowing through the spiral 1, that the spiral itself is not appreciably heated. Consequently in the operation of the device to heat a material, there is no sensible amount of heat transferred by the mechanism of conduction from a hot spiral to the material being treated. To the contrary the heat-

ing of the material is effected exclusively by action thereon of the high frequency electrostatic field produced by the spiral conductors.

Fig. 4 shows diagrammatically the equivalent electrical circuit of the Figures 1 to 3 structure above described. Referring to Fig. 4, the equivalent electrical circuit is that of a two-winding transformer, the primary of which comprises the outer coil 16 wound about the tubular insulating case 3, and the secondary of which comprises the spiral 1, having between its successive spaced turns, distributed capacity as indicated by the dotted lines 20 and in shunt thereto, distributed resistance as indicated by the dotted lines 21.

By virtue of the inductance of the spiral and its distributed capacity 20 in shunt thereto, the spiral will be resonant at some particular frequency, depending on known factors, such as the number of turns, spacing between the turns, overall dimensions, etc. and depending also, on the dielectric constant of the material 10 being treated. In consequence of these factors, if the frequency of the high frequency generator 19 supplying the system is varied over a relatively wide range, the caloric power output; i. e., the power which is converted into heat for heating the dielectric material being treated, will ordinarily vary with the generator frequency somewhat as illustrated graphically by curve 22 in Fig. 5, in conformity with the usual frequency response characteristic of a tuned electrical circuit. Thus, at frequencies fairly remote from the resonant frequency f_2 , such as at frequencies f_1 and f_3 , the caloric power output will be relatively low, but will rise rapidly to a maximum value as the resonant frequency f_2 is approached from either direction. For this reason, it is important that the system be operated at or near its resonant frequency. This may be accomplished in various ways: For example, by appropriate design of the spiral in relation to the desired generator frequency, also taking into account such factors as the dielectric constant of the material to be heated, its variation with temperature, etc. In connection with the latter, the temperature of operation may be controlled within limits by appropriately adjusting the rate of flow of the material being heated. Other expedients consist in adjusting the frequency of the generator to the resonant frequency of the system as constructed; or by connecting a physical condenser of suitable value, in shunt to all or a portion of the spiral, thereby to adjust its resonant frequency to a desired value corresponding to that of the generator employed. In connection with Fig. 5, it is to be noted that minor resonance peaks may be superimposed on the overall resonance curve shown, in the event that self-resonance effects occur in one or more sections of the spiral.

Fig. 7 shows diagrammatically such an arrangement wherein a condenser 23 is bridged across the terminals of the spiral 1, for tuning the spiral as a whole to a desired frequency. Fig. 8 shows a somewhat similar arrangement in which, however, a condenser 24 is bridged across but a portion of the spiral 1. These condensers may be variable, as indicated in Fig. 7, or may be fixed, as indicated in Fig. 8. Generally speaking, however, such a condenser is fixed, its value being selected, once and for all, in accordance with the electrical constants of any particular construction employed.

Spirals of the character above described, and energized from a high frequency source as aforesaid, are subject, in some modifications, to the

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occurrence of standing waves along the length of the spiral, resulting in the occurrence of nodes and anti-nodes of current and voltage, tending thereby to produce localized heating effects. In some applications, these localized heating effects may be desirable and hence, sought after, in which case the spiral is designed to produce the same in a desired pattern. Alternatively, such effects can be obtained at desired regions by suitably connecting one or more condensers of appropriate magnitudes across coil portions where the intensified heating is desired, in conformity with the showing of Fig. 8. One or a series of shunt condensers, appropriately spaced, may be used for this purpose. Conversely, by suitably connecting one or more condensers across selected portions of the spiral, the heating effect where initially non-uniform, can be made more uniform, and localized heating effects thereby avoided.

Fig. 6 shows in vertical axial section, a physical embodiment of the arrangement shown schematically in Figs. 7 and 8, including a condenser such as 23 or 24, connected across all or a portion of the spiral 1. Referring to Fig. 6 the condenser preferably takes the form of a vacuum type condenser such as is shown in cross section at 25, and consisting of spaced electrodes, such as 26, 27 housed in an hermetically sealed glass receptacle 28, with conductors such as 29, 30 extending through opposite ends of the receptacle 28 from the electrodes 26, 27 respectively. If the condenser is to be connected across the entire electrode 1, as illustrated in Fig. 6, one conductor, such as 29, is connected to the innermost convolution of the spiral as shown at 31; while the opposite conductor 30, is connected to the outermost convolution of the spiral as indicated at 32. For this latter purpose, the conductor 30 is preferably molded and embedded in one of the end pieces such as 9, of the insulating housing.

In the event it is desired to keep the condenser 25 wholly out of contact with the material, such as the liquid 10, being treated, the inner convolution of the spiral, such as 33, may be completely enclosed and sealed off in a fluidtight joint, as by welding. In this event, pipe connection 13 is of course tapped at such a point through the end piece 8, as to provide access to the adjacent convolution of the spiral. It is to be understood of course, that a number of condensers may be housed in inner convolution 33, if desired, for connection across successive portions of the spiral in the manner indicated in Fig. 8.

Fig. 9 shows a longitudinal axial section, a modification of the invention according to which the material to be treated is progressively fed axially through one or more of the spirals. Referring to this figure, the material to be treated, such as the fluid 40, is caused to flow progressively in the direction indicated by the arrows 41 through a relatively large diameter pipe 42 of insulating material. Within the insulating pipe 42 are disposed in longitudinally spaced relation, one or more of the spirals, such as 43, 44, each consisting of a metal strip, spirally wound in spaced convolution as above described. In this modification, however, the spirals are left open-ended along their lateral edges as shown, and are so mounted that their axes are parallel with the direction of flow of material 40 being treated and as shown in the drawing. The material 40 being treated therefore flows axially and concurrently through the various spaced convolutions, such as 45, 46 of each spiral.

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For energizing each spiral, such as 43 or 44, a conductor such as 47 or 48 is wound one or more times about the insulating tube 42, in superposed relation to the associated spiral, thereby to form an energizing coil such as 49 or 50. The terminals of each coil 49, are connected to the terminals of a high frequency generator, such as that indicated at 51. The coils 49, 50 may, of course, be connected either in series or in parallel to the terminals of generator 51, depending on the particular design. As shown in Fig. 10, they are connected in parallel to the generator.

In accordance with a further modification of the invention, the heating conductors need not take the spiral forms previously described. In the modification of Figs. 10 and 11, heating electrodes comprising spaced metal plates are connected respectively to the opposite terminals of a transformer secondary winding, the primary of which is connected to the high frequency generator. Referring to this modification, the dielectric heating electrodes comprise the spaced parallel metal plates 50, 51, disposed within a coil 52, one terminal 53 of which is connected to and supports the lower plate 51; while the opposite terminal 54 of coil 52 is connected to and supports the upper metal plate 50. The assembly comprising plates 50, 51 and coil 52 is mounted in a tubular housing 55 of insulating material, such as synthetic resin, porcelain, vitreous material, etc., about the outer surface of which is wound in superposed relation to the inner coil 52, an outer coil 56, the terminals 57, 58 of which are connected to the opposite terminals of a high frequency generator 59. A material, such as a liquid 60, to be dielectrically treated, may be caused to flow through the tubular container 55 in the direction of the arrows 61, whereby in passing between the plates 50, 51, it will be acted upon by the high frequency energy.

With this arrangement, the coils 56 and 52 constitute a two-winding transformer, of which the outer coil 56 is the primary which is directly energized from the high frequency source 59, the inner coil 52 constituting the secondary which is magnetically or inductively energized from the primary. The high frequency voltage thus produced across the terminals of the secondary 52 is in turn impressed between the spaced plates 50, 51, which in effect comprise a condenser connected across the secondary winding. The assembly thus constitutes a tuned circuit, to the resonant frequency of which the generator should be adjusted for optimum heating effect as above described.

For more efficient heating of the material 60 being treated, additional plates may, of course, be connected in multiple with plates 50, 51 respectively. Thus, two sets of interleaving plates may be employed connected in multiple respectively to the opposite terminals of coil 52. Such interleaving plates may be plane or may take the form of open-ended, spaced, interleaving rings, etc. conforming to the contour of the tubular duct 55, etc.

We claim:

1. Apparatus for dielectrically heating fluids or fluid-like materials having dielectric properties comprising: a ribbon-like conductive strip shaped in the form of spaced convolutions, with surfaces of the wider dimension of one convolution facing surfaces of the wider dimension of another to thereby form opposed spaced-apart conductor areas having a substantial amount of distributed

capacity therebetween, enclosure means for the material, in which enclosure means such convolutions are mounted for immersion in the material whereby the material forms a dielectric between said conductor areas, and means external to said enclosure means for subjecting said convolutions to a high frequency electromagnetic field of a strength and frequency to energize same and cause substantial dielectric heating of the material by reason of the distributed capacity between said conductor areas.

2. Apparatus for dielectrically heating fluids or fluid-like materials having dielectric properties comprising: a member of sheet-like conductive material generally spirally wound, with surface areas of one convolution facing surface areas of another to form extensive spaced-apart conductive areas having a substantial amount of distributed capacity therebetween, enclosure means for the material, in which enclosure means said member is mounted for immersion in the material to form a dielectric between said areas, and means for energizing said spirally wound member substantially solely by the use of a high frequency electromagnetic field to which the spirally wound convolutions are subjected.

3. Apparatus for heating fluid materials dielectrically, comprising: enclosure means for containing the material to be heated, said enclosure means including a strip of conductive material spirally wound in spaced convolutions, an inner convolution being surrounded by successive outer convolutions, the opposed surfaces of adjacent convolutions providing in conjunction with the fluid material therebetween, substantial amounts of distributed capacity, means including a coil external to said enclosure means substantially coaxial with and inductively related to said spiral strip for inductively energizing the same from a high frequency source, and means including a pair of ducts into said enclosure for progressively feeding the material to be treated between the spaced convolutions.

4. Apparatus for heating fluid materials dielectrically, comprising: enclosure means for containing the material to be heated, said enclosure means including a strip of conductive material spirally wound in spaced convolutions, an inner convolution being surrounded by successive outer convolutions, the opposed surfaces of adjacent convolutions providing in conjunction with the fluid material therebetween, substantial amounts of distributed capacity, means including a coil external to said enclosure means substantially coaxial with and inductively related to said spiral strip for inductively energizing the same from a high frequency source, and means for progressively feeding the material to be treated in a substantially axial direction through the spaced convolutions of said spiral.

5. Apparatus for heating fluid materials dielectrically, comprising: enclosure means for containing the material to be heated, said enclosure means including a strip of conductive material spirally wound in spaced convolutions, an inner convolution being surrounded by successive outer convolutions, the opposed surfaces of adjacent convolutions providing in conjunction with the fluid material therebetween, substantial amounts of distributed capacity, means including a coil external to said enclosure means substantially coaxial with and inductively related to said spiral strip for inductively energizing

the same from a high frequency source, and means including a pair of ducts extending into said enclosure for progressively feeding the material to be heated between the spaced convolutions of said spiral and along substantially spiral paths extending between the inner and outer convolutions thereof.

6. Apparatus for heating materials dielectrically, comprising: a conductor consisting of a metal strip spirally wound to provide spaced convolutions, a pair of insulating end plates engaging the opposite edges of said spiral conductor, respectively, to provide a fluid-tight spiral passageway therethrough, a duct extending through one of said end plates to an inner convolution of said spiral, and a duct extending to the outer convolution thereof, for progressively feeding material to be dielectrically treated through said spiral passageway, and means insulated from said spiral for inductively energizing the same from a high frequency source.

7. Apparatus for dielectrically heating materials, comprising: a conductor consisting of a metal strip spirally wound in spaced convolutions, a pair of insulating end plates engaging the opposite edges of the spiral conductor, respectively, to provide a fluid-tight spiral passageway for said material between the inner and outer convolutions of the spiral, means providing access for said material to an inner convolution of the spiral and also to an outer convolution thereof, and a coil disposed about said spiral and constructed and arranged for connection to a source of high frequency current, for inductively energizing said spiral conductor from such high frequency source.

8. Apparatus for heating fluid material dielectrically, comprising: a strip of conductive material spirally wound in spaced convolutions, insulating members engaging the opposite edges of such spiral respectively, to provide a substantially fluid-tight passageway spirally therethrough between inner and outer convolutions thereof, means for supplying material to be treated to said passageway, including a pair of ducts having access to the inner and outer convolutions of said spiral respectively, and means for inductively energizing said electrode from a high frequency source, said means including a coil surrounding said spiral and substantially coaxial therewith.

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